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AUTHOR Hubbs-Tait, Laura
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ABSTRACT

A task was developed to differentiate the reasoning of elementary school students in fifth, sixth, and seventh grades. Subjects completed 16 matrices containing two, three, or four dimensions and varying in the embeddedness of the dimensions. They also solved a formal operational task assessing ability to isolate, exclude, and include variables. Participants were told to look at the eight filled cells of each matrix in order to determine the missing ninth picture. Drawings of the figure which subjects thought completed each matrix were scored for the proportion of dimensions differing from those of the correct figure. Error scores revealed that fifth grade students made more errors across all types of matrices. Only seventh grade students made no more errors of four-dimensional figures than they did on figures with three dimensions. Inclusion of interactions on the formal operational task correlated with error scores on two- and three-dimensional matrices, but not with matrices having four dimensions. It is concluded that results confirm the hypothesis that matrix problem solving continues to develop during pre- and early adolescence and is related to the emergence of formal operational thought. (RH)

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Transitions in the Reasoning of Pre- and Early Adolescents:

A New Method of Assessment

Laura Hubbs-Tait

Washburn University

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Paper presented at the Sixteenth Annual Symposium of the Jean
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Abstract

A task consisting of 16 nine-cell matrices was developed to differentiate the reasoning of fifth, sixth, and seventh graders. Matrices contained two, three, or four dimensions. Subjects also solved a formal operational task. Drawings of the figure subjects thought completed the ninth cell of each matrix were scored for the proportion of dimensions differing from those of the correct figure. Analysis of these error scores revealed that fifth graders made more errors across all types of matrices. Only seventh graders made no more errors on four- than three-dimensional matrices. Inclusion of interactions on the formal operational task correlated with error scores on two- and three- but not four-dimensional matrices.

Transitions in the Reasoning of Pre- and Early Adolescents:

A New Method of Assessment

The method of assessment that I am going to be talking about today is a matrix task. On the overhead and in Figure 1 of your handouts is an example of one of the matrices used in this task. The literature on the development of matrix problem solving makes two different claims. On the one hand, the ability to solve matrix problems is thought to be a concrete operational skill, one fully achieved at least by the age of 10 (Caruso & Resnick, 1973; Inhelder & Piaget, 1964; MacKay, Fraser, & Ross, 1970; Overton & Brodzinsky, 1972). On the other hand, the ability to solve matrix problems is thought to be related to the capacity to solve problems requiring formal operational thought (Inhelder & Piaget, 1958; Martorano & Zentall, 1980; Sternberg & Rifkin, 1979).

Can these two claims be resolved? One possibility is that matrix problem-solving abilities do indeed stop developing by the age of 10 (or younger) and are also logically necessary to the subsequent development of formal operational thought. Another possibility is that matrix problem-solving skills continue to develop during pre- and early adolescence and are also related to the concurrent emergence of formal operational abilities.

This paper reports the results of a test of this latter hypothesis. In order to test it a matrix task was

constructed. There were 16 nine-cell test matrices. Eight were taken or adapted from Raven's Standard or Advanced Progressive Matrices (Raven, 1956, 1965). The remaining eight were constructed by the author to be similar to the others. These 16 matrices varied systematically in terms of the number of dimensions they contained (two, three, four) and the embeddedness of these dimensions (independent, dependent). Figures 1 and 2 depict two-dimensional matrices. The matrix in Figure 1 has independent dimensions; the one in Figure 2 has dependent dimensions. Matrices with dependent dimensions are so called because if the attributes of one dimension are set to null then the attributes of the other dimension are automatically cancelled out as well. Setting to null the shape dimension of Figure 2 also cancels out the open/closed X whole/half dimension. The distinction between dependent and independent dimensions is similar to Sternberg's (Sternberg & Rifkin, 1979) distinction between integral and separable attributes. Sternberg and Rifkin (1979) have found that problem-solving strategies differ between analogies with separable versus integral attributes.

Method

Subjects

The matrix task and a formal operational task were administered to 33 fifth graders (17 males, 16 females), 27 sixth graders (14 males, 13 females), and 31 seventh graders

(18 males, 13 females). The mean ages of the students in each grade were 10.8, 11.9, and 13.1 years.

Matrix task

Materials and procedure. Subjects were told to look at the eight filled cells of each matrix in order to determine the missing ninth picture. They were given answer sheets and told to draw their solution for each matrix in the appropriate space. Each subject was allowed two attempts at drawing the solution to each matrix.

Scoring. Subjects' drawings were scored for the number of incorrect dimensions they contained. For example, on the two two-dimensional matrices depicted in Figures 1 and 2, the number of incorrect dimensions could range from zero to two. On a three dimensional matrix, the number of incorrect dimensions could range from zero to three. The scores for the two attempts per matrix were averaged and converted to proportions by dividing by the total number of dimensions inherent in that particular matrix. Thus, dimensions in error scores ranged from 0.0 to 1.0 for each matrix. Interrater reliability on the incorrect dimensions in the drawings of 25 randomly selected subjects was high, ranging from .93 to 1.0 ($M=.99$).

Formal operational task

Materials and procedure. Approximately one month after

solving the matrix task, subjects also solved a formal operational task. The task consisted of the five cards you see pictured in Figure 3. It is a modification of Kuhn and Brannock's plants task; instead of a single independent variable affecting the outcome as is true in Kuhn and Brannock's (1977) task, a two-way interaction affects the outcome. Subjects were asked to suppose that the dogs pictured on the first four cards were their own and that they had raised them very carefully from birth, giving them the three objects drawn on each card, in order to enter them in a dog show. The results of the dog show are indicated by the dog's winning or losing status. Subjects were then shown the fifth card and asked whether a dog receiving those three things would win or lose the dog show and why. Subjects were then asked whether the brush or comb had anything to do with the dogs' winning or losing status and why. Finally, subjects were asked whether the vitamins had anything to do with whether the dogs won or lost and why.

Each of these questions assessed subjects' knowledge of one formal operational scheme, that is, one component of formal operational thought (for a more detailed discussion, see Hubbs-Tait, in press). The first question assessed isolation, subjects' ability to determine which of multiple variables is operative in one specific case: the dry food

depicted on the fifth card would cause the dog to lose. The second assessed exclusion, subjects' ability to exclude an irrelevant variable: the brush and the comb have nothing to do with winning or losing. The third assessed inclusion, subjects' ability to include both food and vitamins in interaction as operative. The isolation and exclusion schemes were scored from 0 to 2; the inclusion scheme was scored from 0 to 3. Percent agreement between two raters on protocols of 30 randomly selected subjects was 73% for isolation, 100% for exclusion, and 90% for inclusion.

Results

Differences between pre and early adolescents

Table 1 presents the results of an analysis of variance of the dimensions in error scores. Significant main effects were found for Grade, $F(2, 85) = 6.63$, $p < .005$; Dimensions, $F(2, 170) = 178.28$, $p < .0001$, and Dependence, $F(1, 85) = 238.10$, $p < .0001$. Fifth graders' drawings of solutions to the matrix task contained more incorrect dimensions than did sixth or seventh graders' drawings. All subjects' drawings contained significantly fewer incorrect dimensions on matrices with two dimensions than on those with three or four dimensions. Similarly, drawings of solutions to three-dimensional matrices contained significantly fewer incorrect dimensions than drawings of solutions to

four-dimensional matrices. Finally all subjects' drawings consisted of fewer incorrect dimensions on matrices with independent dimensions than on those with dependent dimensions.

The above main effects were qualified by a significant two-way interaction between Grade and Dimensions, $F(4, 170) = 3.94$, $p < .01$, and a significant three-way interaction between Grade, Dimensions, and Dependence, $F(4, 170) = 2.86$, $p < .05$. As Table 1 suggests, on two dimensional matrices sixth graders' drawings contained fewer incorrect dimensions than those of fifth graders regardless of whether the dimensions were dependent or independent. On dependent matrices seventh graders also made significantly fewer errors than fifth graders. However, on three- and four-dimensional matrices differences between grades were qualified by whether dimensions were dependent or independent. On matrices with dependent dimensions, performance was consistently poor across all three grades on both three- and four-dimensional matrices. On matrices with independent dimensions, whereas sixth graders' performance exceeded that of fifth graders on three-dimensional matrices, seventh graders' performance exceeded that of fifth graders on four-dimensional matrices.

Relation to formal schemes

Table 2 summarizes the relationships between each scheme

and error scores on each type of matrix. The isolation scheme is positively related to incorrect dimensions on two matrices. Recall that isolation refers to the subject's being able to indicate that dry food will cause the dog in the fifth card to lose. Thus, the more able the subject is to isolate dry food as the inappropriate variable, the greater the number of incorrect dimensions in the subject's drawings on two of the 16 matrices.

The exclusion and inclusion schemes are both negatively correlated with incorrect dimensions. That is, the higher the subject's level of reasoning on these two components of formal operational thought, the fewer the number of incorrect dimensions contained in the subject's drawings on the matrix task. As Table 2 indicates, it is particularly the ability to include the interaction between two variables which predicts matrix task performance.

Discussion

These results confirm the hypothesis that matrix problem solving continues to develop during pre and early adolescence and is related to the emergence of formal operational thought. Note however, that this conclusion must be qualified in two important respects. First, errors do not decrease across all types of matrices during pre and early adolescence. On three- and four-dimensional matrices with dependent dimensions, the proportion of incorrect dimensions

is constant across the fifth, sixth, and seventh grades. Thus, mastery of these types of matrices is not complete during this period and presumably continues to develop during early adolescence. Second, not all aspects of formal operational thought are related to matrix problem solving. The relationship between isolation and exclusion, on the one hand, and matrix problem solving, on the other, is only minimal. However, that between inclusion, or identification of an interaction between variables and matrix problem solving is not.

The finding that errors decrease during pre and early adolescence on matrices with independent dimensions but are close to floor on three- and four-dimensional matrices with dependent dimensions is at variance with the results of Foorman, Sadowski, and Basen (1985) who found that the accuracy of both fifth and eighth graders was near ceiling on matrices with independent dimensions. The difference between the current study and the earlier one is not merely that the current investigation included matrices with dependent dimensions. Foorman, et. al.'s (1985) outcome measure was the accuracy of subjects' designations of researcher selected solutions as true or false. Does this difference in outcome measures and results between the two studies reduce to a production deficit in fifth graders? That is, do fifth

graders perform accurately when required to judge but not produce solutions but not perform accurately when required to produce them? No, research by Sternberg and Rifkin (1979) on visual analogies (different from figural matrices in several respects) also revealed highly significant age differences when subjects were not required to produce their own answers but had to judge which of two answers was the correct one. The more similar the correct and the incorrect answer, the more difficult it was for younger subjects to designate the correct solution. Thus, the difference between the current investigation and Sternberg and Rifkin (1979), on the one hand, and Foorman, et. al. (1985), on the other, is that the former two studies allow for the fact that errors are not alike. Some are better than others; they indicate more understanding on the part of the subject. It is not in the production of errors that developmental differences lie, it is in the difference between kinds of errors, whether produced or judged.

The discrimination in this study between those components of formal operational thought which are related to matrix problem solving and those which are not qualifies the finding by Martorano and Zentall (1980) that training on matrix tasks facilitates performance on formal operational tasks. The results of the current study suggest that it is the understanding of interactions between variables that is

related to matrix task performance more so than the ability to exclude irrelevant variables or to isolate significant main effects. It is particularly noteworthy that the relationship between including interactions on the formal operational task and matrix task performance is not restricted to one type of matrix, but generalizes to matrices with both dependent and independent dimensions and to matrices with both two and three dimensions.

Nonetheless, there were no significant correlations between dimensions in error scores on the four-dimensional matrices and scores on the inclusion scheme of the formal operational task. A careful examination of the four-dimensional matrices in figure 4 reveals that they consist of two two-dimensional matrices, one composed of horizontal figures and one composed of vertical figures. Thus, these matrices are higher-order matrices, involving the multiplication of two matrices. Inhelder and Piaget (1958) suggest that it is this type of problem involving relations between relations which is soluble by formal operational adolescents. This assumption is certainly consistent with the superior performance of the seventh graders on the four-dimensional independent matrices in the current study. However, the absence of significant negative correlations between any of the formal operational schemes assessed on the

dogs task and matrix task errors suggests that performance on this particular formal operational task is not related to performance on higher-order matrices. It may be that performance on higher-order matrices is related to performance on more complex combination of variables tasks, those involving four or more variables. Alternatively, higher-order matrix task performance may be related only to formal operational tasks which assess relational reasoning (Demetriou & Efklides, 1985).

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Table 1

Mean Number of Dimensions in Error

Means for Grade

Fifth (N = 33)	Sixth (N = 27)	Seventh (N = 31)
.48	.36	.38

Matrices with Independent Dimensions	Means for Grade			Matrices with Dependent Dimensions	Means for Grade			Means for Dimensions
	5th	6th	7th		5th	6th	7th	
2D	b	a	a, b		b	a	a	.24
	.19	.03	.11		.47	.25	.34	
3D	b	a	a, b		a	a	a	.43
	.38	.19	.27		.60	.55	.56	
4D	b	a, b	a		a	a	a	.57
	.50	.44	.33		.73	.70	.69	
Means for Dependence		.28				.55		

Note: Within each block of independent or dependent dimensions means in each row with different superscripts differ from each other significantly. Means with common superscripts do not differ.

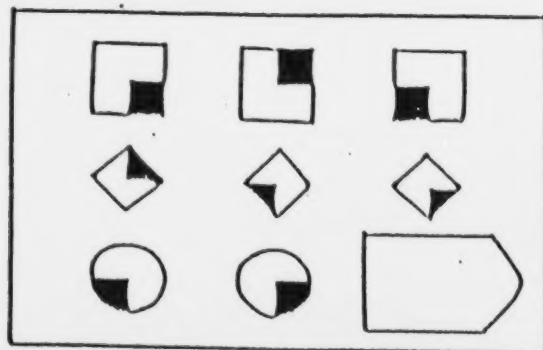
Table 2

First-Order Correlations Between Schemes and Dimensions in Error

Matrices with Independent Dimensions	Exclusion	Isolation	Inclusion
Two Dimensions ($N = 4$)		.23**	-.24**
Three Dimensions ($N = 2$)			-.29*** -.20*
Four Dimensions ($N = 2$)			
Matrices with Dependent Dimensions			
Two Dimensions ($N = 4$)	-.20*		-.25**
Three Dimensions ($N = 2$)	-.21**		-.20*
Four Dimensions ($N = 2$)		.21**	

Note. Grade is partialled out of all correlations. Sample sizes (e.g., $N = 2$) refer to number of exemplars of that type of matrix. One correlation was calculated between each scheme and dimensions in error per exemplar. Only coefficients at the .10 level or lower are reported.

*p (.10.
**p (.05.
***p (.01



Transitions

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Solution:



DIMENSIONS

1. Position x Direction

Down • Right
Down • Left
Up • Right*

2. Shape

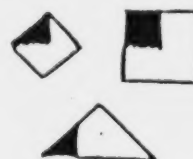
Square
Diamond
Circle*

two dimensions
in error:

COPIED
SOLUTIONS



ORIGINAL
SOLUTIONS



one dimension
in error:

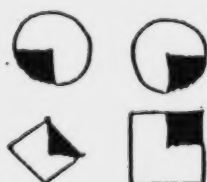
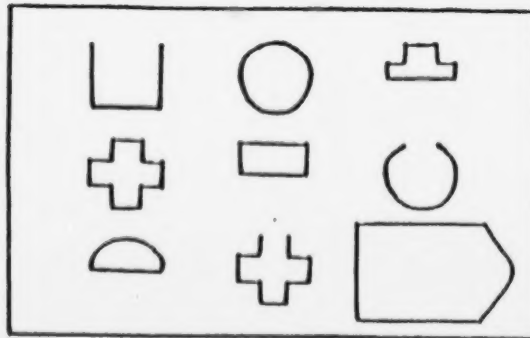


Figure 1. A two-dimensional matrix with independent dimensions and the different types of errors which could be made by subjects.



Solution:



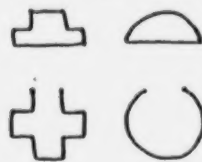
DIMENSIONS

1. Open/Closed x Whole/Half

Closed • Whole*
 Closed • Half
 Open • Whole

2. Shape

Circle
 Cross
 Square*

COPIED
SOLUTIONS

two dimensions
 in error:

ORIGINAL
SOLUTIONS

one dimension
 in error:

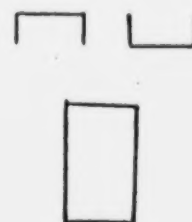
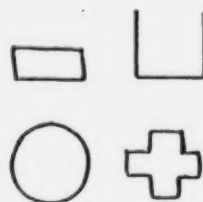


Figure 2. A two-dimensional puzzle with dependent dimensions and the different types of errors which could be made by subjects.

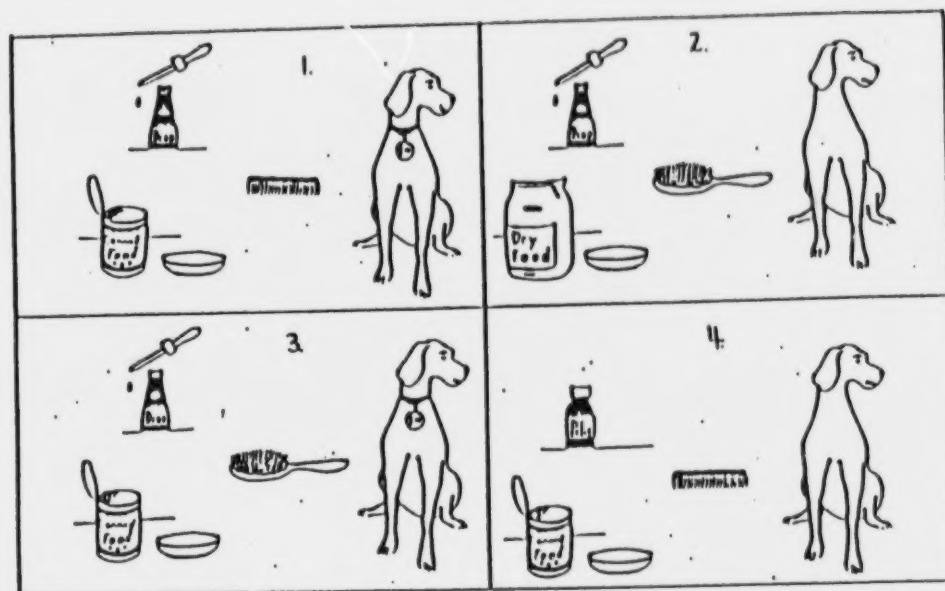
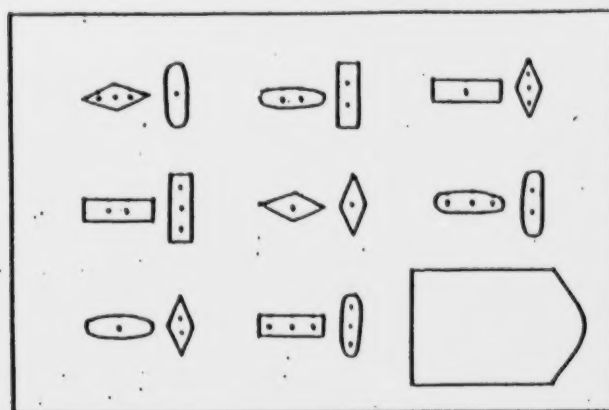
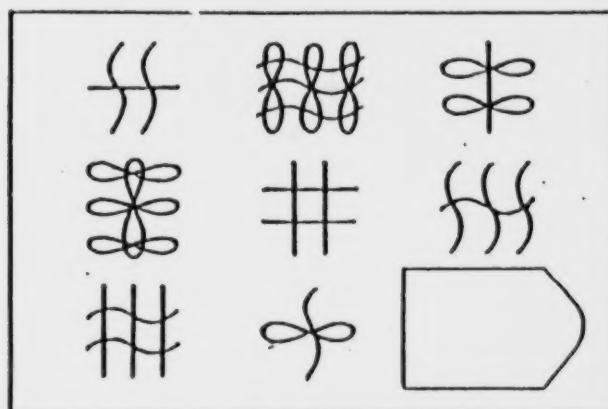


Figure 3. Cards shown to subjects on the formal operational task.



Solution:  



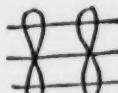
Solution: 

Figure 4. Four-dimensional matrices.